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PDMS Anatomical Models for Hemodynamic Studies Using Rapid Prototyping Technology

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Introduction

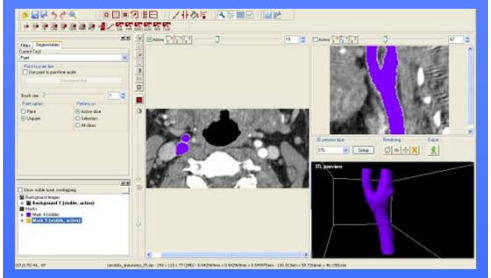
In vivo hemodynamics studies in animals it is considered to be essential to validate computational hemodynamics models, as real physiological situations can be mimicked. However, in vivo studies are expensive, difficult to control several physiological variables, and most of the times the measurements are not accurate. Over the years, *in vitro* experiments have been developed to overcome those limitations, but most of them had used simple and rigid geometries and not physiologically shaped. Hence, it is important to investigate new fabrication techniques to manufacture anatomically realistic artery models to obtain accurate measurements of the blood flow behavior in both macro and micro *in vitro* arteries ahead of in vivo studies.

The **main purpose** of this work is to **investigate a simple way of making polydimensiloxane (PDMS) anatomically artery models** such as a carotid arteries with and without aneurysm. By using a human carotid computerized tomography (TC) it was possible to develop 3D anatomical models through the application of a rapid prototyping (RP) technique, known as tridimensional printing (TDP). By combining the TDP with a PDMS casting technique we were able to obtain at the end an anatomically transparent model of a human carotid artery made by a silicon elastomer, i.e. PDMS.

Materials and methods

Image Processing

Different working plans in ScanIP® software



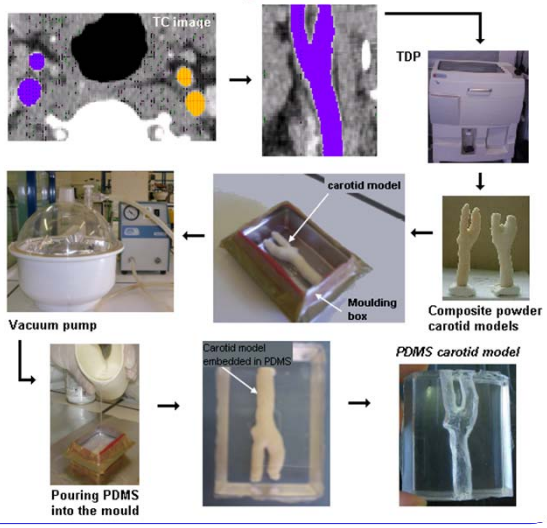
Segmentation process has been performed in the software ScanIP® where TC images can be transferred in DICOM format. To do this step, binarization and thresholding techniques have been applied to the images in order to obtain a mask in a range of grey values that includes, in each image, the tissues from the study object – carotid artery.

Manufacturing PDMS anatomical models

Artery models manufactured by TDP process

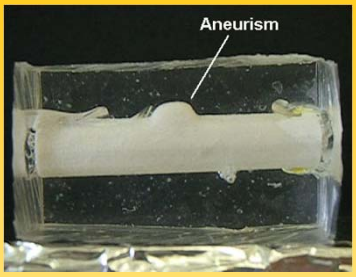
Tridimensional Printing (TDP): In this RP process, the model is built from a composite dust material (a specific combination of materials). In printing process, the composite material is prepared by a cylinder action that flattens the surface each time a layer is printed. In each layer the printing head draws the correspondent section in the material surface in glue aqueous liquid. When the new material is deposited to the new layer, it is glued to the previous one by the cylinder action.

Main steps to manufacture PDMS *in vitro* models of human artery vessels

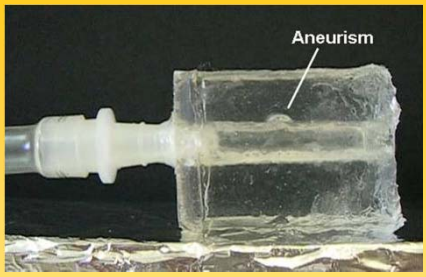


Results and discussion

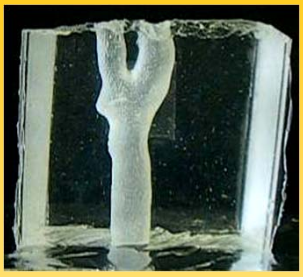
Straight channel with an aneurism embedded in PDMS



PDMS straight channel with an aneurism



PDMS carotid channel



PDMS carotid channel with an aneurism

The embedded models manufactured by the TDP technique were immersed in hydrochloric acid (HCl) for about 15 minutes and then placed in an oven for about 1 hour at a temperature of 60ºC. By using nails and screw drivers it was possible to obtain an anatomically transparent models of a human vessels. The Figures above show that the PDMS models have enough good transparency able to perform blood flow visualization studies. However, it should be pointed out that in the walls of this PDMS models have high levels of roughness due to the rapid prototyping technique used to manufacture the carotid model. In the near future, we are planning to polish the surface of carotid model to decrease roughness of the model. However, it is worth mentioning that we have also observed small amount of the composite powder attached on the wall for several vessels models. Hence, the procedure described above still needs to be improved in the future.

Conclusion and future work

- The PDMS transparent models obtained by the TDP technique seems to be a promising way to perform *in vitro* blood flow studies through anatomically realistic replica of a human carotid artery with and without aneurisms. Currently, an ongoing study to perform flow measurements trough the PDMS anatomical models is under way.